UDC 621.396.029.51/.53
:621.391.827
621.391.832.2

1969
THE QUEEN'S AWARD
TO INDUSTRY

RESEARCH DEPARTMENT REPORT

Reduction of adjacent-channel interference in the l.f. and m.f. broadcast bands by reduction of the modulation bandwidth

No. 1971/10

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

REDUCTION OF ADJACENT-CHANNEL INTERFERENCE IN THE L.F. AND M.F. BROADCAST BANDS BY REDUCTION OF THE MODULATION BANDWIDTH

Research Department Report No. **1971/10**

UDC 621.396.029.51/.53
:621.391.827:
621.391.832.2

It uses SI units in accordance with B.S. document PD 5686

D. Maurice

C.R.G. Reed, M.A.,(Oxon), C.Eng., M.I.E.E.

Head of Research Department

(RA-72)

Research Department Report No. 1971/10

REDUCTION OF ADJACENT-CHANNEL INTERFERENCE IN THE L.F. AND M.F. BROADCAST BANDS BY REDUCTION OF THE MODULATION BANDWIDTH

April 1971

Research Department Report No. 1971/10
UDC 621.396.029.51/.53
:621.391.827:
621.391.832.2

REDUCTION OF ADJACENT-CHANNEL INTERFERENCE IN THE L.F. AND M.F. BROADCAST BANDS BY REDUCTION OF THE MODULATION BANDWIDTH

Summary

Transmitter carrier frequencies in the l.f. and m.f. broadcast bands assigned under the Copenhagen Plan of 1946 are, for the most part, separated by 9 kHz. Transmitters and receivers operating in these bands are usually designed for a modulation bandwidth greater than 4·5 kHz although the receiver response may be appreciably attenuated at frequencies above 2 kHz. As a result the spectra of adjacent channels overlap and there is adjacent-channel interference. This report considers the possibilities of reducing this interference by the use of low-pass filters at the a.f. inputs to the transmitters, without undue degradation of programme quality, taking into account the frequency-response characteristics of typical receivers. Filter frequency-response characteristics are proposed for use at l.f. and m.f. transmitters.

1. Introduction

Low-frequency and medium-frequency broadcast transmitters in Europe, as in many other parts of the world, are becoming more numerous and more powerful, resulting in increased levels of co-channel and adjacent-channel interference.

Consider two broadcast transmitters operating on the same or adjacent frequency channels. Around each transmitter there is a primary service area in which the field strength from that transmitter is so high that, even under adverse propagation conditions, no interference with reception is caused by the other transmitter. Outside each of these primary service areas there are secondary service areas in which reception is subject to interference for part of the time, the intensity of the interference depending on several factors which include:

(i) the field strength of the wanted signal at the receiver,

(ii) the field strength of the interfering signal at the receiver,

(iii) the bearings of the wanted and interfering transmitters relative to the receiver, and the receiving aerial's horizontal polar diagram,

(iv) the propagation conditions at the time: those affecting groundwave propagation are normally stable while those affecting sky-wave propagation may at times vary widely and rapidly,

and, in the case of adjacent-channel interference,

(v) the modulation bandwidths of the transmitters and the receiver.

The present study is restricted to the last of these factors.

2. Theoretical considerations

2.1. General

The choice of the modulation bandwidth of a broadcast transmission is a compromise between giving the widest possible audio bandwidth, which is mainly of benefit in the primary service area, and minimising interference in the secondary service areas of other transmissions in the adjacent channels.

Until recently the former consideration has been dominant, although the number of receivers able to take full advantage of the service has been very small and of these only a very small proportion are in areas where the Band II f.m. transmissions would not give an even better service. In the last few years some workers[1,2,3] have considered an approach towards an idealised system in which, for a channel spacing of 9 kHz, the modulation bandwidths of all transmitters and receivers would be sharply limited to ±4·5 kHz. In principle this could eliminate adjacent-channel interference.

Within the primary service area a substantial cut in transmitter modulation bandwidth would be serious for the small minority of listeners who have high quality l.f./m.f. receivers but with a suitably chosen filter the difference in the quality of reception with typical receivers may be small. On the other hand, in the secondary service area it could give some improvement in adjacent-channel interference for listeners with typical receivers provided that potentially interfering transmitters adopted a similar bandwidth restriction. An important aspect of the change would be that it could justify manufacturers in producing receivers with improved characteristics. Such receivers (which might employ mechanical-resonance i.f. filters and integrated-circuit active a.f. filters) would probably be slightly more

expensive than those now manufactured: they would, however, be capable of giving appreciably better reproduction than is obtained with typical existing receivers.

Fig. 1 illustrates typical spectral responses at the transmitter and at the receiver. The range of frequencies involved in adjacent-channel interference is shown as a shaded band TR where T is the lower limit of the sideband spread of the interfering transmission and R is the upper limit of the receiver pass-band. It is seen that transmitter and receiver modulation-bandwidth restriction each has its part to play in the rejection of adjacent-channel interference and neither can be very effective by itself.

2.2. Envelope detection

When two amplitude-modulated signals, with different carrier frequencies and at very different amplitudes, are present simultaneously at the input to a linear detector the a.f. output contains components which are not part of either modulation while the modulation of the weaker signal appears at a much lower level than it would be in the absence of the stronger signal.[4,5,6]

Let the signal with the greater amplitude, normally the wanted signal, be

$$E_{\mathrm{w}} \cos \omega_{\mathrm{w}} t = A_{\mathrm{w}}(1 + m_{\mathrm{w}} \cos p_{\mathrm{w}} t) \cos \omega_{\mathrm{w}} t$$

and the signal with the smaller amplitude

$$E_{\mathrm{a}} \cos \omega_{\mathrm{a}} t = A_{\mathrm{a}}(1 + m_{\mathrm{a}} \cos p_{\mathrm{a}} t) \cos \omega_{\mathrm{a}} t.$$

The difference between the angular frequencies of the two carriers is

$$\omega_{\mathrm{d}} = \omega_{\mathrm{a}} - \omega_{\mathrm{w}}$$

and the ratio of their unmodulated carrier amplitudes is

$$K = A_{\mathrm{a}}/A_{\mathrm{w}}.$$

The output from a linear detector at any instant may be taken as being equal to the amplitude of the signal at the input to the detector and is given by

$$E_{\mathrm{tot}} = \left\{E_{\mathrm{w}}^2 + E_{\mathrm{a}}^2 + 2E_{\mathrm{w}}E_{\mathrm{a}} \cos \omega_{\mathrm{d}} t\right\}^{1/2}$$

which may be written

$$E_{\mathrm{tot}} = E_{\mathrm{w}}\left\{1 + x^2 + 2x \cos \omega_{\mathrm{d}} t\right\}^{1/2} \qquad (1)$$

where $x \equiv E_{\mathrm{a}}/E_{\mathrm{w}}$

It is shown in Reference 6 that $\left\{1 + x^2 + 2x \cos \omega_{\mathrm{d}} t\right\}^{1/2}$ may be expanded as a series and

$$\begin{aligned} E_{\mathrm{tot}}/E_{\mathrm{w}} = {} & \left(1 + \frac{x^2}{2^2} + \frac{x^4}{2^6} + \ldots\right) \\ & + x\left(1 - \frac{x^2}{2^3} \ldots\right) \cos \omega_{\mathrm{d}} t \\ & - \frac{x^2}{4}\left(1 - \frac{x^2}{2^2} - \frac{5x^4}{2^7} \ldots\right) \cos 2\omega_{\mathrm{d}} t \\ & + \frac{x^3}{8}\left(1 - \frac{5x^2}{2^4} \ldots\right) \cos 3\omega_{\mathrm{d}} t \qquad (2) \\ & \text{etc} \end{aligned}$$

which is convergent if $x < 1$.

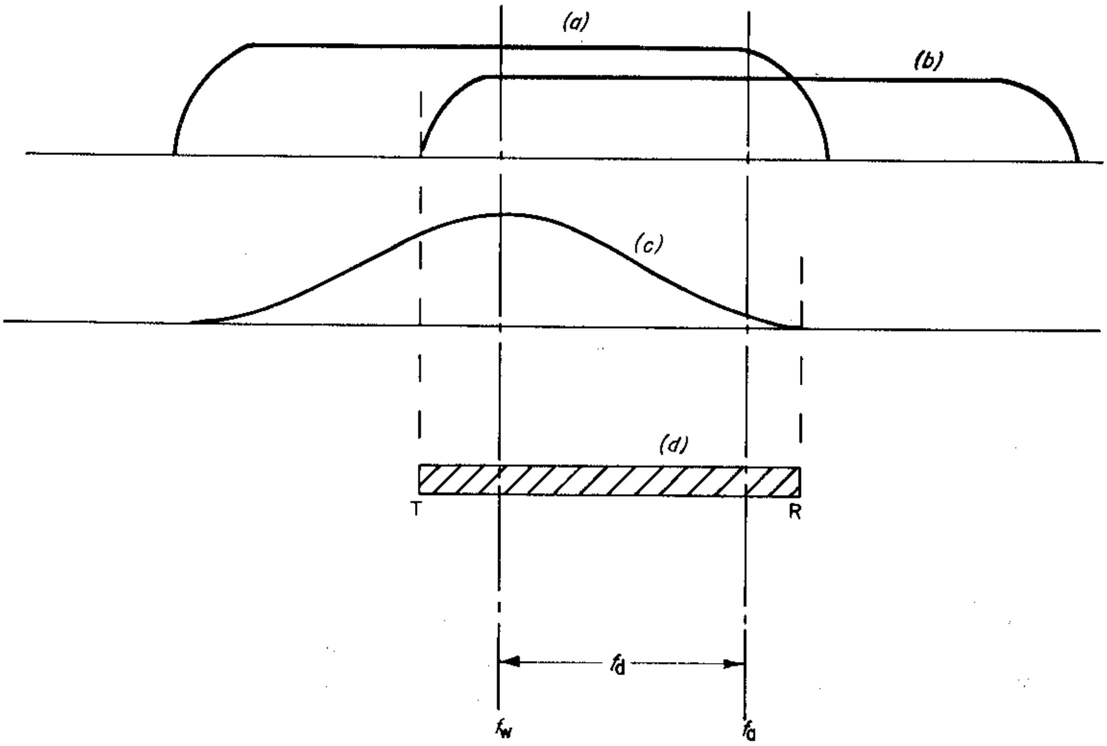

Fig. 1 - Spectra of wanted and adjacent-channel transmissions and the receiver pass-band

(*a*) Spectrum of wanted transmission (*b*) Spectrum of adjacent-channel transmission (*c*) Receiver pass-band (*d*) Possible frequency range of interference

Interference is normally most perceptible in gaps in the modulation of the wanted signal, i.e. when $m_w = 0$ and $E_w = A_w$.

Then $x = K(1 + m_a \cos p_a t)$

The first bracket in the expansion for E_{tot} (Equation 2) is

$$E_w(1 + x^2/4 + x^4/64 \ldots.)$$

$$= A_w[1 + K^2(1 + m_a \cos p_a t)^2/4 + K^4(1 + m_a \cos p_a t)^4/64 \ldots] \quad (3)$$

Convergence of Equation (3), for $0 < m_a \leqslant 1$, requires that K should be less than 0·5.

The third term of Equation (3) may be neglected and the expansion has three components:

a d.c. component

$$A_w[1 + \tfrac{1}{4}(1 + \tfrac{1}{2}m_a^2)K^2] \quad (4)$$

a fundamental-frequency component

$$\tfrac{1}{2}A_a K m_a \cos p_a t$$
$$= \tfrac{1}{2}A_w K^2 m_a \cos p_a t \quad (5)$$

and a second-harmonic component

$$\frac{A_a K m_a^2 \cos 2p_a t}{8}$$
$$= \frac{A_w K^2 m_a^2 \cos 2p_a t}{8} \quad (6)$$

The amplitude of the fundamental component is thus ($\tfrac{1}{2}K$) of what it would have been in the absence of the stronger signal – equivalent to a depth of modulation $\tfrac{1}{2}K^2 m_a$ of the wanted carrier – and the amplitude of the second-harmonic component is ($\tfrac{1}{4}m_a$) of the fundamental. Both of these components are small for moderately small values of K.

Returning to Equation (2), the second term gives as a component of E_{tot}

$$E_w x(1 - x^2/8 \ldots.) \cos \omega_d t$$

$$= A_w K(1 + m_a \cos p_a t)\left[1 - K^2(1 + m_a \cos p_a t)^2/8 \ldots.\right] \cos \omega_d t \quad (7)$$

If K is small this reduces to

$$A_w K(1 + m_a \cos p_a t) \cos \omega_d t \quad (8)$$

i.e. the modulation of the interfering signal appears on the beat between the signals and the effect can be considered as the sum of three components whose amplitudes are proportional to K:

$$A_w K\left[\cos \omega_d t + \tfrac{1}{2}m_a \cos(\omega_d - p_a)t + \tfrac{1}{2}m_a \cos(\omega_d + p_a)t\right] \quad (9)$$

The first of these components is a steady tone at a frequency equal to the carrier separation. The last component is usually at a frequency above 9 kHz and is of little importance. The middle component is usually important, consisting of an inversion of the spectrum of the modulation of the interfering signal and being responsible for the 'monkey-chatter' characteristic of adjacent-channel interference.

The relative amplitudes of the detector outputs discussed in this section will be considered in the following section in relationship to the frequency response characteristics of the receiver and the relative strengths of the wanted and interfering signals.

2.3. The frequency-response characteristics of the receiver

The previous section dealt with the signals at the input to and the output from the detector of the receiver. These are related to the r.f. inputs from the aerial and the acoustic output from the loudspeaker by the frequency-response characteristics of the r.f./i.f. stages and of the a.f. stages (including the loudspeaker).

Two hypothetical receiver characteristics are considered, (Fig. 2).

Receiver 1: a receiver having characteristics based on the mean of four receivers* which were the subject of an earlier Report.[7]

Receiver 2: a receiver having the same overall modulation characteristic as Receiver 1 but with the r.f./i.f. response flat to approximately ±16 kHz, all the response limitation being provided by the a.f. stages.

Both receivers are assumed to have ideal linear detectors and to be free from non-linear distortion.

Table 1 gives the calculated values of the i.f. components at the detector input and the a.f. components at the detector output and the loudspeaker output for each receiver, at a carrier separation of 9 kHz, for values of $K \equiv A_a/A_w$ of 0·5, 0·1 and 0·05 with sinusoidal modulation of the interfering signal to a depth of 90% first at 2 kHz

* These measurements were made by K. Hacking in the course of other work related to the reception of m.f. broadcast programmes.

TABLE 1

Calculated adjacent-channel interference levels in two hypothetical receivers

	Mod. frequ. kHz	Detector/Receiver output	K = 0·5		K = 0·1		K = 0·05	
			Rec. 1	Rec. 2	Rec. 1	Rec. 2	Rec. 1	Rec. 2
1		Detector output at 9 kHz	−35	−6	−49	−20	−55	−26
2		Receiver output at 9 kHz	**−61**	**−61**	**−75**	**−75**	**−81**	**−81**
3	2	Detector output at 7 kHz	−36	−13	−50	−27	−56	−33
4	2	Detector output at 11 kHz	−48	−13	−62	−27	−68	−33
5	2	Detector output at 2 kHz	−77	−19	−105	−47	−117	−59
6	2	Receiver output at 7 kHz	**−52**	**−52**	**−66**	**−66**	**−72**	**−72**
7	2	Receiver output at 11 kHz	**−83**	**−83**	**−97**	**−97**	**−103**	**−103**
8	2	Receiver output at 2 kHz	**−76**	**−19**	**−104**	**−47**	**−116**	**−59**
9	6·5	Detector output at 2·5 kHz	−16	−13	−30	−27	−36	−33
10	6·5	Detector output at 6·5 kHz	−57	−19	−85	−47	−97	−59
11	6·5	Receiver output at 2·5 kHz	**−16**	**−16**	**−30**	**−30**	**−36**	**−36**
12	6·5	Receiver output at 6·5 kHz	**−70**	**−53**	**−98**	**−81**	**−110**	**−93**

All tabulated values are in dB relative to level corresponding to 100% modulation of the wanted signal by 1 kHz tone in the absence of interference.

$$K = \frac{\text{Interfering carrier amplitude}}{\text{Wanted carrier amplitude}} \text{ at receiver input}$$

Channel separation 9 kHz

Wanted signal not modulated

Interfering signal simusoidally modulated 90% at (i) 2 kHz (ii) 6·5 kHz

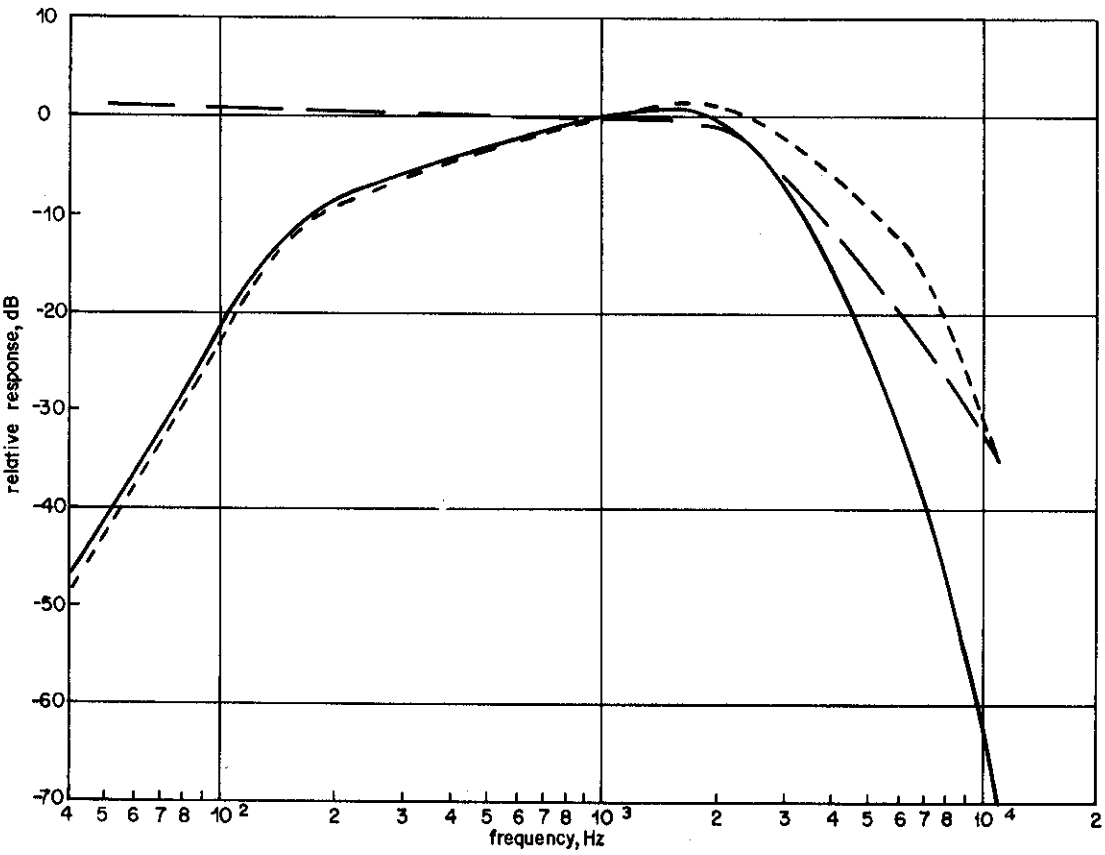

Fig. 2 - Characteristics of hypothetical receivers

——— Over-all frequency response of either receiver, a.f. response of Receiver 2

— — — r.f./i.f. response of Receiver 1   - - - - a.f. response of Receiver 1

and then at 6·5 kHz. The figures show that the most important a.f. components involved in adjacent-channel interference in an average receiver are

i) the 'inverted' spectrum produced as the beat between the wanted carrier and the nearer sidebands of the interfering signal (Lines 7 and 11), particularly at high modulating frequencies,

ii) the beat between the two carrier frequencies.

Comparing the results for the two receivers in both Line 8 and Line 12 of Table 1 shows the important part played by pre-detector selectivity in suppressing the direct appearance of the unwanted modulation at its original frequency (cf. Section 2.2, Equation 5). Conversely, Lines 2, 6 and 11 show that it is the overall response of the receiver that determines the levels of the inter-carrier beat at 9 kHz and of the inverted frequency spectrum due to sidebands of the interfering signal. Thus the receiver selectivity characteristics can be chosen to give protection against the interfering carrier and the sidebands due to low frequency components of its modulation at the expense of the high frequency components of the wanted signal but they cannot give protection against the sidebands due to high frequency components of the interfering modulation (which appear as low frequency components of the receiver's output) without causing impairment of the middle- and low-frequency components of the wanted signal.

2.4. The characteristics of the transmitter

The modulation bandwidth of a transmitter may be limited by inserting either an a.f. low-pass filter into the modulation chain or by inserting an r.f. bandpass filter after the modulated amplifier. The former is preferred because it is cheaper not only in the lower cost of the components but also in giving a slight saving in the power required by the modulator and the modulated amplifier. An a.f. filter, however, would not prevent the radiation of sidebands due to harmonic distortion in the modulator and modulated amplifier which is typically of the order of 5% at depths of modulation between 90% and 95%. At greater depths of modulation the distortion rises rapidly and the resulting sidebands may be a significant factor in adjacent-channel interference, as well as causing appreciable degradation of the wanted signal.

A programme limiter is usually employed at the audio input to a transmitter. This is a peak-limiting amplifier in which the gain of the signal channel is constant when the signal amplitude is below a prescribed level, but an increase in the input signal above this level is offset by a reduction in gain that, apart from very short transients,[8] prevents the output level from exceeding the prescribed limiting level L (Fig. 3). When the input signal falls below the limiting level the gain recovers at a controlled rate.

The average modulation depth of a programme may be raised by increasing the audio level at the input to a limiter of this type. Alternatively, a compressor may be used; as far as BBC equipment is concerned the operation is very similar to that of a limiter. The essential difference is clear from the static characteristics of a BBC Limiting Amplifier type AM6/3A shown in Fig. 3 for the limiter mode and the compressor mode of operation.

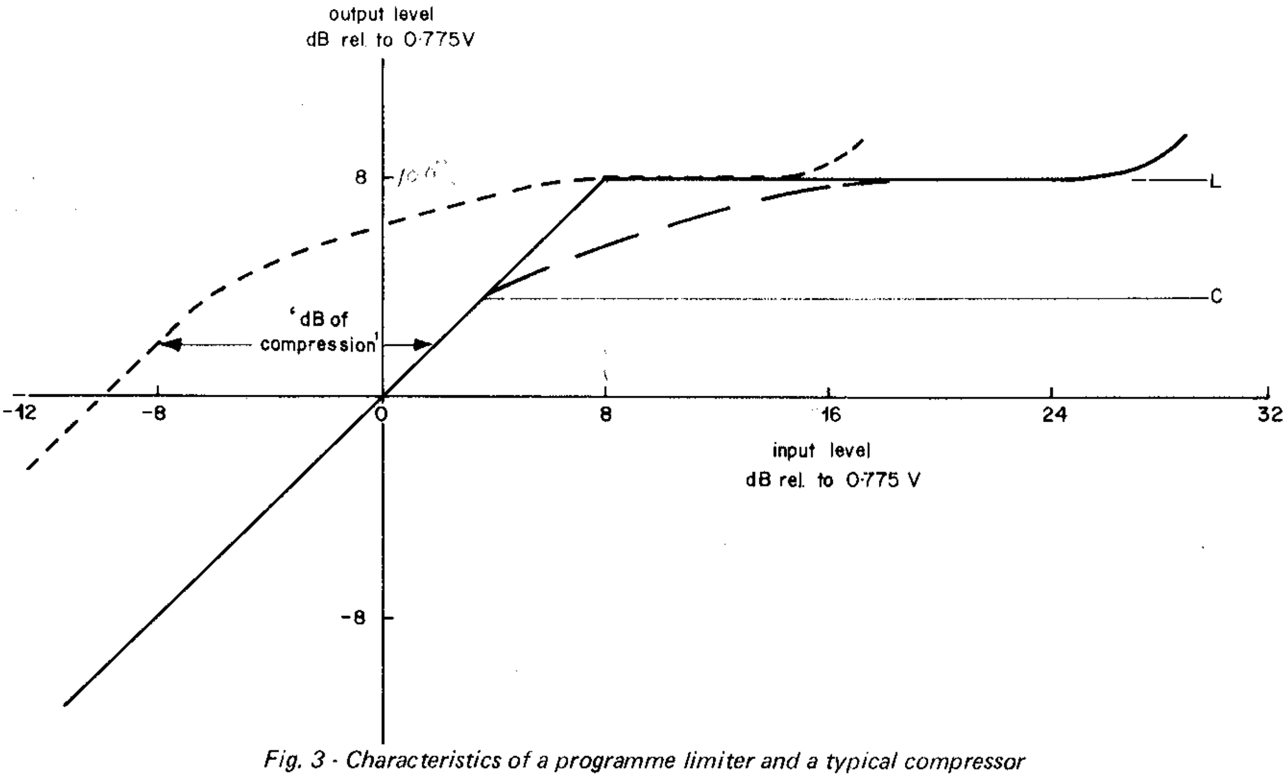

Fig. 3 - Characteristics of a programme limiter and a typical compressor

C Threshold of compression (Output level below which compressor has constant gain) L Output limiting level

——— Limiter characteristic, no compression — — Compressor characteristic, 0 dB of compression

– – – – Compressor characteristic, 10 dB of compression

The operating conditions considered in this report are such that:

(i) When the 'dB of compression' control on the compressor is set to zero and the input signal amplitude is below the compression threshold level the output signal amplitude is the same as the input signal amplitude.

(ii) The limiting level of the output signal and the nominal peak level of the input signal are equal, and normally set at +8 dB. Excessive modulation is prevented by control of the gain between the compressor and the modulator.

(iii) When the 'dB of compression' control is set to C dB and the output level is below the threshold of compression the gain of the compressor is C dB.

(iv) The threshold of compression and the limiting level, measured at the output from the compressor, are independent of the setting of the 'dB of compression' control.

The Limiting Amplifier AM6/3A in its compressor mode of operation – as used in the tests described in this report – has a threshold of compression at its output of +4 dB relative to 0·775 V as indicated in Fig. 3. For settings of the 'dB of compression' control not exceeding about 10 dB, the output level is below the limiting level when the input is at its normal peak amplitude – apart from the momentary overshoots mentioned earlier in connection with limiters – and with the 'dB of compression' control at zero the output at normal peak signal level is 2 dB below the input.

2.5. The programme chain

When the programme feed to an l.f./m.f. transmitter is by line from London (e.g. the Radio 2 programme radiated by the l.f. transmitter at Droitwich) it may be convenient for operational reasons to install the compressor at the studio centre where the degree of compression may be adjusted to suit the programme material, particularly if part of it has been recorded with some amplitude compression (e.g. a commercial disk recording) and replayed without a corresponding expansion. If a bandwidth limiting a.f. filter with a cut-off frequency of approximately 5 kHz is used it should generally be placed before the compressor. This protects the compressor from being operated unnecessarily by signal components in the 5 to 15 kHz range which are not transmitted and also ensures adequate response to any peaks of signal that may have been enhanced by the use of a filter characteristic giving a slight boost over part of the frequency range. It is important that there should still be a programme limiter at the transmitter to prevent overmodulation distortion due to changes in the peak level of the programme at the input to the transmitter arising from changes in the lines or the repeater amplifiers.

When a wide-bandwidth uncompressed signal is provided at the transmitter site the filter would form part of the Programme Input Equipment, preceding the compressor which would also serve as the limiter preventing overmodulation of the transmitter. It might not then be practical to vary the degree of compression according to the programme content, particularly at remotely-controlled transmitters.

2.6. Objective methods of assessing interference

It has been suggested[2,3,9,10,11] that objective measurements of adjacent-channel interference should replace subjective tests, which would clearly lead to a great saving of time.

One aspect of such methods of measurement is that they require a standard test signal which represents the interfering modulation and a standard meter which indicates the receiver output in a way that represents the annoyance effect of the interference. One possible standard modulating signal is random noise whose spectrum is weighted to be statistically equivalent to the relevent type of programme. However, adjacent-channel interference in the l.f./m.f. broadcast band is characterised by bursts of sound, corresponding to the syllabic structure of the programme, separated by gaps in which little or no interference is perceptible. While a weighted-noise signal may, over a time interval of say, a minute, represent the average of the peaks of energy at particular frequencies it is unlikely to represent the grouping of energy peaks of a real programme. It is possible that a more suitable signal than continuous random noise for energising the weighting network would be an irregular sequence of audio-frequency tones keyed bv irregularly-spaced pulses of varying width.

The second aspect of the subjective methods is that the device that indicates the interference level at the receiver output should assess its annoyance value. Although there is an internationally agreed psophometric weighting curve for this purpose[9] it is of limited value, not only because the importance of different parts of the frequency spectrum appears to vary with the level of the interference but also, and of greater importance, because the indicator should reflect the amplitudes, widths and rate of occurrence of the peaks of the interference and not just its long-term average. Even if such a measuring device could represent the simpler aspects of the annoyance value of interference it is unlikely that it could represent the more subtle aspects such as rhythmic patterns that are not perfectly regular.

Because of these difficulties the experimental work described in this Report has been based on subjective assessments of interference using the following six-point impairment scale (CCIR Report 405, Note 2)[12].

Grade	Impairment
1	Imperceptible
2	Just perceptible
3	Definitely perceptible but not disturbing
4	Somewhat objectionable
5	Definitely objectionable
6	Unusable

3. Experimental work

3.1. Subsidiary tests on the levels at which interference is just perceptible

Before tests were made relating to the effectiveness of a.f. filters in reducing adjacent-channel interference, two subsidiary tests were made on the dependence of the audibility of interference, in the form of a steady tone, on the level of the wanted signal.

3.1.1. Tests at audio frequency

Tests at audio frequency were made to check whether the level at which interference is perceptible depends on the level of the wanted programme. The outputs from a tape machine, replaying a recording of a male news-reader, and from an a.f. tone source were controlled by separate attenuators and added linearly, the total signal being reproduced on a high-grade loudspeaker with a volume control. Adjustment of either attenuator varied one signal without affecting the volume of the other, and variation of the loudspeaker volume control affected both inputs equally. For each participant in turn the output from the tone source was heavily attenuated, the output from the tape replay machine was set to a standard volume and the participant adjusted the loudspeaker volume control to the loudness that he preferred. The loudspeaker volume control was then left untouched throughout that participant's series of tests. The a.f. tone source frequency was set to 9 kHz and the participant was asked to adjust the attenuator controlling its output level to make the interference 'just perceptible' (Grade 2 on the six-point impairment scale). The attenuator controlling the volume of the replayed speech was set to +5, 0 and −5 dB relative to its initial setting, repeating the settings in a random sequence, and the 'just perceptible' level of tone was found for each volume of the wanted signal. The frequency of the tone was then changed to 8 kHz and 7 kHz in turn and the procedure repeated.

It was found that, for any one participant using a fixed setting of the loudspeaker volume control and a constant frequency tone, the just-perceptible level of the tone was independent of the volume of the wanted signal. The results differed considerably, though, between one participant and another and, for any one participant, for different frequencies of the tone and different settings of the volume control. The interference was apparent during the gaps in the speech; the results were similar when the wanted programme consisted of some types of music at the same peak levels, such as *cantabile* piano passages, but could be significantly different for those types of music in which there is a fairly constant volume with no significant breaks in the sound.

The implication of this is that, under normal listening conditions with programmes in which there are short pauses (i.e. those programmes during which interference is most noticeable) and when the interference is predominantly a 7 to 9 kHz tone, it is the level of the interference that determines its audibility rather than its ratio to the volume of the wanted programme.

3.1.2. Tests at radio frequency using an unmodulated interfering signal

Further tests were performed analogous to those described in Section 3.1.1 but at r.f. An r.f. carrier at approximately 1 MHz was amplitude modulated by the wanted programme and the interference was produced by an unmodulated carrier at a controlled spacing above the frequency of the wanted carrier. The two signals were combined and fed into the car aerial socket of a transistor portable receiver which was accurately tuned to the wanted signal with the interfering signal at a very low level. When the carrier level of the wanted signal was changed the receiver a.g.c. system varied the r.f./I.f. gain by less than the change in the input signal level, allowing the volume of the wanted signal output from the receiver to vary. The 'just perceptible' level of the interfering signal was found to depend on the carrier level of the wanted signal but the two were not in constant ratio.

This shows that very great care is required when comparisons are made between the results for different receivers or even between the results for the same receiver under different operating conditions.

3.2. Tests on adjacent-channel interference using standard receivers

3.2.1. Tests with an interfering signal modulated by pure tone

In these tests the 'wanted' signal was an m.f. carrier modulated to a depth of 90% by recorded male speech while the 'interfering' signal was a carrier of controlled level, at a frequency 9 kHz higher, modulated to a depth of 80% by a tone whose frequency could be varied between 0·5 and 9·0 kHz. The two signals were again combined and fed into the car radio socket of a transistor portable receiver which was tuned accurately to the wanted signal with the interfering signal at a very low level. Two observers, one between 20 and 30 years of age and the other between 40 and 50, in separate tests, each set the volume control of the receiver to a pleasing level and then without changing this setting, adjusted the interfering carrier level so that the interference was 'just perceptible' for various frequencies of the tone modulation. For a given modulation frequency the ratio of the just-perceptible level of the interfering signal to the corresponding level when the modulation frequency is 7 kHz (i.e. an audible tone out of the receiver at 2 kHz) is shown for each observer in Fig. 4, together

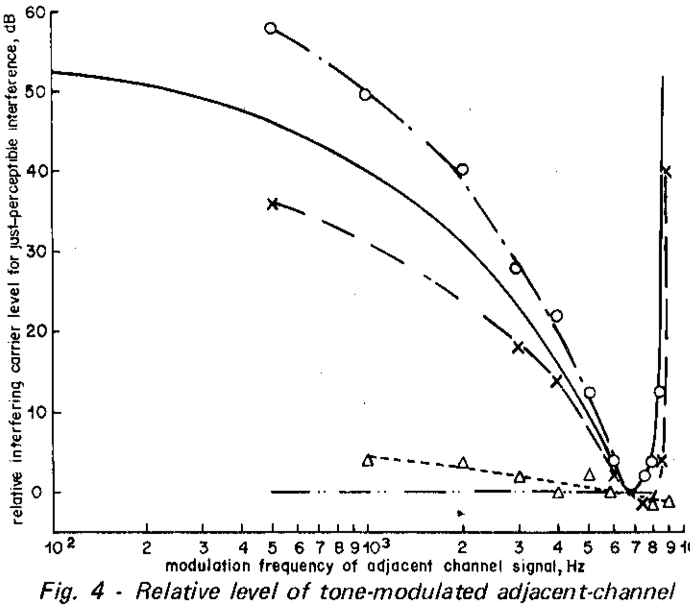

Fig. 4 - Relative level of tone-modulated adjacent-channel signal for just-perceptible interference, normalised to a modulation frequency of 7 kHz

Observer 1 —×— —×— } Using transistor portable receiver; –△– – –△– } Using high grade check receiver
Observer 2 —○— · —○— }

———— Curve derived from objective receiver response (Ref. 7)

with a curve derived by combining the overall frequency response averaged over four receivers[7] with the latest CCIR noise weighting curve[9].

A similar series of tests was made using a high-grade check receiver with a modulation bandwidth greater than 10 kHz feeding a high-grade loudspeaker. It was found that the 9 kHz beat between the carriers was of great significance to the first observer, the 'just-perceptible' level of interfering signal only varying by 6 dB over the full range of the modulation frequency, while it dominated the results for the second observer who found no variation of just-perceptible carrier level with modulation frequency.

These tests show that if the receiver has a high response at the inter-carrier beat frequency (9 kHz) the just-perceptible level of adjacent-channel interference is almost independent of the frequency of the tone modulation of the interfering signal, but if the response at 9 kHz is poor, as is typical of domestic receivers, the combined system of the receiver and the ear is most sensitive to a tone modulation frequency of approximately 7 kHz resulting in a receiver output frequency of approximately 2 kHz.

3.3. First series of tests* with programme modulation of the interfering signal

3.3.1. The receivers

Tests were carried out early in 1968, to determine the effects on adjacent-channel interference of restricting the transmission modulation bandwidths by sharp-cut 4·5 kHz low-pass filters. Five receivers were used in these tests, identified by the letters A to E. A, B and C were transistor portables of then current or recent type from British manufacturers, D was a German transistor portable and E, a British valve table model about 15 years old. Tone controls of the transistor portables, where fitted, were adjusted for the widest-range frequency response. In the case of the valve receiver, which had a single control varying both i.f. bandwidth and audio-frequency amplifier response, the control was set to give the maximum overall bandwidth consistent with the narrower of the two available i.f. bandwidths.

3.3.2. Programme modulation

The wanted signal was modulated with male speech (a news reading) and the interfering signal with light music giving a continuous high level of modulation. These programmes were recorded on parallel tracks of a twin-track tape, to ensure that the same combination of programmes were used in all tests, and the audio-frequency signals, after replay, were compressed by 10 dB. The peak steady-state outputs of the compressors produced 85% modulation of the signal generators which provided the r.f. signals and each compressor was followed by a symmetrical peak clipper set to clip at the 95% modulation level to prevent overmodulation on transients. There was no perceptible cross-talk between the channels on either output from the recorder.

Low-pass filters with a nominal cut-off frequency of 4·5 kHz (characteristic (*a*) in Fig. 5) could be switched into the two modulation circuits at the inputs to the compressors. The upper frequency limit of the modulation channels in the absence of the low-pass filters was not measured but was at least 10 kHz.

3.3.3. Test procedure

The wanted signal at a frequency of approximately 1 MHz was injected into the receiver under test at a level equivalent to a field strength of 5 mV/m at the ferrite aerial; with the table model receiver, which did not incorporate a built-in aerial, the applied signal was 5 mV open-circuit e.m.f. in a standard dummy aerial, simulating an effective aerial height of 1m with the same field strength.

For each observer, the receiver was carefully tuned by the operator with no interference present and the observer was asked to adjust the audio gain control to his own preference. The operator then adjusted the level of the interfering signal until the observer assessed the subjective effect of the interference as 'perceptible' (Grade 3 on the six-point impairment scale), and the ratio of wanted to interfering carrier levels was noted. This is the protection ratio required by the receiver. The test was carried out with frequency separations between the wanted and interfering signals of 0, ±7, ±8 and ±9 kHz with no bandwidth restriction and ±7, ±8 and ±9 kHz with 4·5 kHz low-pass filters in the modulation channels of both signals. The tests were presented to the observer in random order.

The tolerances on the frequency separations were ±20 Hz for the nominal zero, and ±70 Hz for the nominal 7, 8 and 9 kHz.

These tests were carried out by six observers on each receiver but not necessarily the same six in each case, since a total of nine observers, all technical personnel of BBC Research Department, took part.

3.3.4. Results for the first series of tests

Table 2 gives a summary of the test results in the form of the protection ratios required for co-channel inter-

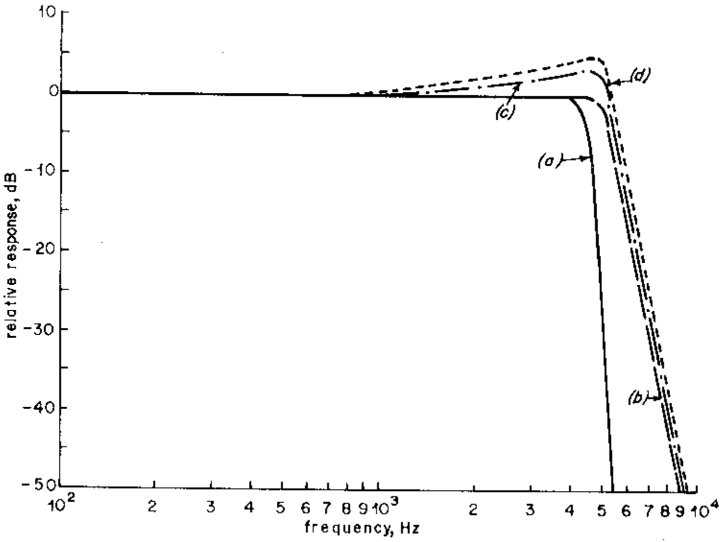

Fig. 5 - Responses of bandwidth limiting filters

(*a*) ———— sharp cut-off at 4·5 kHz
(*b*) —— —— moderate rate of cut-off at 5 kHz
(*c*) —— - —— as (*b*), but with 3 dB of top lift
(*d*) — — — —.— as (*c*), but with 5 dB of top lift

* The work described in Section 3.3 was carried out by J.G. Spencer.

ference and the 'relative protection ratios' for adjacent-channel interference, i.e. the required protection ratio for adjacent-channel interference minus that for co-channel interference. This relative protection ratio is compared with the CCIR recommendation for transmissions employing a high value of audio compression. This term 'mean' in this and subsequent tables refers to the arithmetic mean of the values expressed in decibels.

It was noticed during the tests that observers differed in their assessments both of the absolute level of interference classed as perceptible, and of the relative levels with different frequency separations. Table 3 shows the results for each of the four observers who made assessments for all five receivers.

TABLE 2

Protection ratios for 'perceptible' interference Mean of results for six observers

Receiver	A	B	C	D	E	Mean	Ref. 10 Curve B
	dB	dB	dB	dB	dB	dB	dB
r.f./i.f. response relative to peak							
±7 kHz rel. to carrier	−21	−16	−14	−19	−21	−18	
±8 kHz	−25	−20	−16	−22	−26	−22	
±9 kHz	−29	−25	−19	−27	−30	−26	
Protection ratio for co-channel interference	29·7	29·0	28·2	26·7	29·9	28·7	
Relative protection ratio for adjacent-channel interference, unrestricted bandwidths							
Channel spacing ±7 kHz	−14·0	−4·5	0	−3·0	−6·4	−5·6	−13
±8 kHz	−20·6	−11·5	−7·5	−14·9	−16·3	−14·2	−21
±9 kHz	−26·1	−20·5	−15·4	−20·2	−23·4	−21·1	−28
Improvement in protection ratio for adjacent-channel interference when transmission modulation bandwidths are restricted to 4·5 kHz							
Channel spacing ± 7 kHz	0·5	0·2	1·0	−0·6	0·3	0·3	
± 8 kHz	1·9	−0·1	0·7	0·6	1·6	0·9	
± 9 kHz	4·8	1·8	2·8	3·9	4·4	3·5	

TABLE 3

Protection ratios for 'perceptible' interference Mean of results for five receivers

Observer	1	2	3	4
	dB	dB	dB	dB
Protection ratio for co-channel interference	32·8	29·5	20·5	28·4
Relative protection ratio for adjacent-channel interference, unrestricted bandwidths				
Channel spacing ± 7 kHz	−4·7	−12·0	−4·0	−4·1
± 8 kHz	−14·6	−17·0	−10·2	−13·7
± 9 kHz	−23·2	−23·5	−17·3	−19·3
Improvement in protection ratio for adjacent-channel interference when transmission modulation bandwidths are restricted to 4·5 kHz				
Channel spacing ± 7 kHz	0·1	0·6	0·7	0·2
± 8 kHz	0·3	2·2	0·6	1·1
± 9 kHz	3·3	3·5	3·3	3·2

3.3.5. Discussion of results in the first series of tests

It is apparent from Table 2 that, although the more selective receivers tend to require lower protection ratios against adjacent-channel interference and to gain more benefit from the restriction of transmission bandwidth, it is not possible to predict the protection ratio for any given channel separation from the i.f./r.f. response alone. This is understandable, since the response of the audio-frequency portion of the receiver including the loudspeaker has a considerable influence on the performance, but no attempt was made at the time of these tests to measure the overall acoustical modulation-frequency response of the receivers. Table 3 shows that, despite the large divergence of opinion between the various observers as to absolute levels of interference, there was quite close agreement on the effects of bandwidth restriction on the protection ratio required.

It will be seen from Tables 2 and 3 that, for the five receivers tested, the low-pass filter gave about 3·5 dB improvement in adjacent-channel interference when the channel spacing was 9 kHz but there was little benefit when the spacing was 8 or 7 kHz.

3.4. Second series of tests with programme modulation

After the completion of the tests described above four other models of receiver became available. In the course of other work measurements were made of their frequency responses[7] (cf. Sect. 2.3) and the opportunity was taken of extending the tests described in Section 3.3 above to these receivers. Six observers determined the levels at which an interfering signal was 'Perceptible' at channel spacings of 9, 8 and 7 kHz, first with wide-band modulation and then with the transmission modulation bandwidths of both signals limited by sharp-cut 4·5 kHz fitlers (characteristic (*a*) of Fig. 5).

When the channel spacing was 9 kHz the averaged results of six observers assessed the improvements in the rejection of adjacent-channel interference by the four receivers that were tested as 6·2, 6·0, 4·2 and 2·8 dB. These values are slightly higher than those found in the previous tests (Table 2) but the difference is no greater than might be expected from receivers of generally more recent design heard under difference listening conditions. There was close correlation between the improvement in protection ratio resulting from the insertion of the filter and the rejection at 9 kHz provided by the overall response (from aerial input to loudspeaker output) of the receivers.

At channel spacings of 8 and 7 kHz the filter improved the protection against adjacent-channel interference by less than 2 dB — which is consistent with the values given in Table 2 — and there was virtually no correlation with the overall response at a modulation frequency equal to the channel separation frequency.

3.5. The effects of alternative band-restricting filters on interference at a clearly perceptible level

For this series of tests one representative receiver was tuned to the wanted signal in the absence of interference. The wanted modulation was then switched off and the interfering signal added at the same carrier level as the wanted signal. This resulted in considerably higher levels of interference than had been used in the previous tests, and involved different criteria in the assessment of the effects of band restricting filters.

The interfering signal was 90% modulated by Latin-American music with 10 dB of compression, the bandwidth being limited either by the characteristics of the signal generator (to about 10 kHz) or by a filter.

Seven filters were used in these tests:

Filter (i) The '4·5 kHz sharp-cut' filter referred to in Section 3.3.2 whose characteristic is given by curve (*a*) of Fig. 5.

Filter (ii) A 4·5 kHz filter with a moderate rate of cut-off which has the same attenuation at 4·5 kHz as Filter (i).

Filter (iii) A 5 kHz filter with a sharp cut-off, having the same rate of cut at Filter (i).

Filter (iv) A 5 kHz filter with a moderate rate of cut-off having the same response at 5 kHz as Filter (iii). Its characteristic is given by curve (*b*) of Fig. 5.

Filter (v) A 5 kHz slow-cut filter which has the same response at 5 kHz as Filter (iii) and Filter (iv) and an attenuation of 20 dB at 10 kHz.

Filter (vi) A 6 kHz fast-cut filter which has 6 dB attenuation at 6 kHz and the same rate of cut as Filter (i) and Filter (iii).

Filter (vii) A 7 kHz fast-cut filter, similar to Filter (vi) except that the nominal cut-off frequency is 7 kHz.

Filters similar to Filter (i) had earlier been installed at the l.f. transmitter at Droitwich and a few m.f. transmitters but their effects on the wanted programme were criticised. Filters with the characteristics of Filter (ii) have been used in a similar way in Germany and their effects appear to be acceptable.

Twenty-five listeners, in groups varying in size between two and eight, compared the subjective effects of the interference with various bandwidth limitations. Time was not available for tests embracing numerical grading of the impairments and the assessments made are purely descriptive. It is convenient to consider the change from one of these filters to an adjacent one in order of severity of cut, or from Filter (vii) to the condition in which there is no separate filter, as a single step although this does not involve any implications regarding the relative sizes of the steps. The single step that produced the greatest subjective effect was that between Filter (vii) (7 kHz bandwidth) and Filter (vi) (6 kHz bandwidth), which involves the removal from the receiver output of interference components between 2 kHz and 3 kHz, a range where both the receiver and the ear are near to peak sensitivity. (cf. Figs. 2 and 4). The three-step change from Filter (i) (4·5 kHz filter with sharp cut-off) to Filter (iv) (5 kHz filter with moderate rate of

cut-off) makes a comparatively small difference to the subjective effect of the interference although each of the three steps alone is perceptible to nearly all of the listeners. It was the general consensus of opinion that the effect of the 4·5 kHz sharp-cut filter, compared with wide-band modulation was, at this level of interference, far more dramatic than might have been expected from the changes in the 'perceptible but not disturbing' levels of interference reported in Sections 3.3 and 3.4.

For reasons discussed in Section 3.6, the response of Filter (iv) was modified from that of curve (*b*) in Fig. 5 to curve (*c*). This modification caused only a marginal degradation in the subjective effect of the interference which still was appreciably less serious than when any of the wider-band filters was used. Further tests were made later to assess the effects of this modification to the filter response on the level at which interference becomes perceptible (see Section 3.7).

3.6. The effects of the limitations of transmitter modulated bandwidth on the quality of reproduction of the wanted programme

3.6.1. Laboratory tests

The twenty-five participants in the tests described in Section 3.5 also listened (during the same sessions) to the effects of the filters, both alone and combined with three available top-lift characteristics, on the quality of the wanted programme as reproduced by representative receivers. The results were not graded numerically but the consensus was that characteristic (*c*) of Fig. 5 was a satisfactory compromise; increasing the bandwidth made little difference to the quality of the wanted programme but considerably worsened the adjacent-channel interference heard under the conditions of Section 3.5, while removing the top-lift or narrowing the modulation bandwidth caused an appreciable worsening of the quality of the wanted programme without significantly reducing the effects of adjacent-channel interference.

The tests described above were made on the m.f. broadcast band. The frequency response of the Droitwich l.f. transmitter shows a loss of approximately 1 dB at 5 kHz and, although receivers differ appreciably, the response to 5 kHz modulation tends to be approximately 1 dB lower on the l.f. band than on the m.f. band, giving a total difference between the l.f. and m.f. services of approximately 2 dB. Curve (*d*) of Fig. 5 shows a characteristic in which the top lift has been increased by 2 dB over that of curve (*c*), and the use of the former at Droitwich and the latter on m.f. transmissions should give similar reproduction by typical receivers, except for minor effects of the extra top lift on the action of the limiter at the transmitter.

3.6.2. Tests using broadcast signals

Tests have been made* in which listeners to seven m.f. broadcast transmitters were asked to compare the effects of each of two filters (characteristics (*a*) and (*c*) of Fig. 5) relative to wide-band modulation for five types of programme material using the seven-point comparison scale (CCIR Report 405 Note 4).[12]

The tests showed that the 4·5 kHz sharp-cut filter produced a noticeable degradation of reception quality which would probably be detected by a small but critical minority of listeners. The 5 kHz filter with 3 dB of top lift produced a much smaller effect which is unlikely to be reliably detected by the public on any programme material except male speech for which the difference is beneficial.

3.7. A comparison between the effects of two filter networks on adjacent-channel interference

3.7.1. Test conditions

Five observers took part in tests which compared the effects on adjacent-channel interference of the two degrees of bandwidth restriction of the interfering signal that appeared to be of greatest interest in the light of the previous tests. Three receivers were used, two of recent (1970) manufacture which were not fitted with tone controls, while the third (which was older) was used under two conditions, first with its treble tone control set to mid position and then with its treble set nearly to minimum. Each of the four listening conditions was assessed by three observers, but none of them observed all four conditions.

The wanted signal was modulated by male speech (a news reading) with a basically narrow bandwidth that was not reduced further by filters. The modulation of the interfering signal was light music that could be broad-band or could be restricted by either of two filters with characteristics given by curves (*a*) and (*c*) in Fig. 5. Both modulations were amplitude compressed but without the a.f. peak clippers that had been used in the first series of tests (of Section 3.2.2).

Each observer was asked to tune the receiver to the wanted channel in the absence of interference, and adjust the volume control to a comfortable level. He was then asked to set the level of the interfering signal, on a carrier frequency 9 kHz higher than the wanted signal, so that the interference was 'Just Perceptible' (Grade 2 on the EBU six-point scale) using wide-band modulation. The modulation bandwidth of the interfering signal was then switched randomly between the three bandwidth conditions and the observer found the 'Just Perceptible' interference level for each condition.

3.7.2. Results

The results of the tests are given in Table 4. The pass-band of one receiver was wide and the transmission filter made little difference to the susceptibility to adjacent-channel interference, the 9 kHz inter-carrier beat being produced strongly. For the other receivers, the value of transmission bandwidth filtering was greatest when the receiver bandwidth was least, the improvement due to the 4·5 kHz filter (Fig. 5(*a*)) ranging from 6 to 13 dB while that for the wider filter (Fig. 5(*c*)) was 4 dB less for these receivers.

* By the BBC Engineering Information Department.

TABLE 4

'Just Perceptible' levels of interfering signal with restricted modulation bandwidth in dB relative to that for broad-band modulation

Filter characteristic	5(*a*)	5(*c*)	Difference
Receiver I	0	1	1
II	2	6	4
III, medium bandwidth	4	8	4
III, narrow bandwidth	9	13	4

Summarising these results, if the receiver pass-band is wide transmission pass-band limitation offers no advantages. If the receiver pass-band is narrow, the wider response filter can offer a considerable improvement over broad-band transmission, but 4 dB less advantage than a 4·5 kHz filter.

3.8. The effects of variation of the modulation bandwidth of the receiver on adjacent-channel interference

3.8.1. General considerations

Although the primary purpose of this Report is to consider the effects of the limitation of transmitter modulation bandwidth when using existing receivers, consideration must also be given to the equally important influences of the receiver characteristics on the overall quality of an l.f./m.f. broadcast service.

One of the receivers used in the tests had a break-jack from which an external audio system could be fed, at the same time disconnecting the internal loudspeaker. The frequency response using an external wide-band amplifier and speaker was considerably wider at both the treble and the bass then when the receiver's internal a.f. system was used, but the response was not measured.

3.8.2. Some measurements on the effects of restriction of the a.f. bandwidth of the receiver

A few tests were made in which low-pass filters were inserted both between the source of the interfering modulation and the signal generator and between the receiver output jack and the loudspeaker. At the time of the tests six filters were available, two having the characteristic given as curve (*a*) in Fig. 5 with a 4·5 kHz cut-off frequency, one with a cut-off at 5 kHz, one at 6 kHz and two at 7 kHz. All had similar fast rates of cut-off.

The wanted signal was first modulated by male speech; the receiver was then accurately tuned to it and its volume control adjusted by the observer to produce an acceptable output from the loudspeaker. The wanted modulation was then switched off. The interfering carrier, at a frequency 9 kHz above the wanted signal, was 90% modulated by Latin-American music, using 10 dB of volume compression; both the interfering modulation fed into the signal generator and the receiver output fed into the loudspeaker were band limited. For each combination of modulation and reception bandwidth the carrier level of the interfering signal was found for which the interference was 'just perceptible' (Grade 2 on the EBU scale). Taking as reference condition the restriction of both the transmitter and receiver pass-bands to 7 kHz (the receiver filter eliminating the 9 kHz beat between the carriers) restriction of both bandwidths to 4·5 kHz raised the level at which interference was just perceptible by 12 dB whereas the restriction of either bandwidth to 4·5 kHz while the other remained at 7 kHz only gave an improvement of 3 dB. The results are summarised in Table 5.

TABLE 5

Effects of restricting both transmitter modulation bandwidth and receiver a.f. bandwidth: protection ratio for just-perceptible interference, dB relative to that obtained when both bandwidths are 7 kHz

		Receiver a.f. Bandwidth kHz			
		7	6	5	4·5
Transmitter modulation bandwidth, kHz	7 kHz	0			3
	6			2	
	5		4		
	4·5	3			12

These results are open to question because only one receiver was used, with a very small number of listeners, because the tone balance of the output was very different from that produced by any normal receiver and because the receiver bandwidth limitation was controlled in the a.f. stages. Nevertheless, they show clearly that the reduction of adjacent-channel interference by bandwidth limitation is a function of the combination of the transmitter and receiver characteristics and that both must be controlled if the rejection of interference is to be improved materially.

3.9. The effects of volume compression on adjacent-channel interference

The effects of volume compression on adjacent-channel interference were not the subject of a specific sereis of tests but conclusions are drawn from relevant aspects of the tests that have already been reported.

Consider an adjacent-channel signal which is fully modulated but is marginally below the 'just perceptible' level. An increase in the carrier level of this signal could make it perceptible, but there is no evidence to suggest that volume compression which left the peak amplitude unchanged could make the interference perceptible.

If the interfering signal were only just perceptible, amplitude compression would raise more of the signal to the just-perceptible level so that interference would be just perceptible for a greater percentage of the time. This could have a marginal effect on the carrier level at which the interference was graded as just-perceptible.

If the interfering signal were above the just-perceptible level, compression would again raise the percentage of the time that the signal reached this level and the subjective effect of the interference would be made worse.

An amplitude compressor without a delay line produces narrow pulses of high-amplitude signal at the start of a sudden loud passage. An increase in the degree of compression, being essentially an increase in gain before the level-detecting stage, exaggerates this effect. Under normal circumstances the excess peaks of signal are of too short duration to be audible. If, however, the compressor were also functioning as the final amplitude limiter (Section 2.5) a fault condition in which the input was at excessively high level, equivalent to a very high degree of compression, could overload the compressor (Fig. 3) and increase the effects of adjacent-channel interference.

4. Discussion and conclusions

Demand for the use of channels in the l.f./m.f. bands is now so great that there are few transmissions that do not either cause or suffer from co-channel or adjacent-channel interference. The effects of adjacent-channel interference between two transmissions with the standard 9 kHz carrier spacing can, however, be improved by limitation of the modulation bandwidths of the transmitter and the receiver. Fortunately, distortion in a transmitter modulation chain with correct operation of the amplitude limiter, is usually sufficiently low to allow a filter to be placed in the audio stages, before modulation, rather than in the r.f. high-power stages.

Until recently it has been normal practice in Europe to modulate l.f./m.f. transmitters with wide-band a.f. signals. Restriction of the modulation bandwidths of transmitters has only a small effect on adjacent-channel interference with existing receivers, but unless some first step is taken by the broadcasters there will be little incentive for industry to develop receivers with frequency responses that would play their part in the reduction of adjacent-channel interference.

Field trials have been made at some BBC transmitters using sharp-cut a.f. filters of 4·5 kHz bandwidth but these have been criticised because of their effects on programme quality. Laboratory tests (Sections 3.3 and 3.4) indicate that they would give a reduction of about 4 dB in adjacent-channel interference when using a typical receiver. Meanwhile West German transmitters use 4·5 kHz filters with a somewhat less rapid rate of cut-off. A 5 kHz filter (curve (*d*) of Fig. 5) with a similar moderate rate of cut-off and a top lift at frequencies between 1 and 5 kHz has been installed in the programme feed to the BBC 200 kHz transmitter at Droitwich and it is hoped that the quality of the received programme will be much more satisfactory with this filter. Meanwhile, a listening test in which the modulation bandwidth of an m.f. transmission was restricted by an equivalent filter (curve (*c*) of Fig. 5) has confirmed that this characteristic does not materially affect the programme quality. Laboratory tests suggest that the reduction in adjacent-channel interference is less though still useful, giving perhaps half the benefit from a 4·5 kHz sharp-cut filter (Section 3.7). Further evidence from field trials is desirable on both the quality of the received programme and adjacent-channel interference.

It is hoped that receiver manufacturers will find it possible to develop, quite soon and at much the same cost as present receivers, models with more rapid attenuation of the i.f. or a.f. response for modulation frequencies above 5 kHz. There is also scope for a type of receiver whose i.f. response is rather more carefully controlled to give a flatter top and steeper skirts as compared with the usual response curve. This could involve an increase in manufacturing costs, either because of added complexity of the circuits or because of the need to develop a new technique such as the use of mechanical i.f. filters, and an interchange of views between broadcasters and industry is desirable to ensure a reasonable compromise between quality and interference rejection.

During this time it is to be hoped that discussions, probably at international level, can recommend a suitable transmitter characteristic. Such discussions may also consider the possibility of reducing the standard channel spacing from 9 kHz to, say, 8 kHz. With typical receivers of current design this would worsen the protection against adjacent-channel interference by about 6 dB. Moreover, with 8 kHz channels the dominant component of the interference would be the 8 kHz beat between the two carriers and there would be negligible benefit from a reduction of the transmitter modulation bandwidth with existing types of receiver. Any such channel width reduction would therefore call for appropriate planning of transmitter frequency and power allocations, for a carefully chosen compromise transmitter modulation characteristic and for the encouragement of receivers with overall responses that could give better adjacent-channel rejection.

The present report has mainly concerned with the first step towards the reduction of adjacent-channel interference, namely a proposed transmitter modulation filter characteristic which is appropriate to a 9 kHz channel width and existing receivers but nevertheless gives scope for receiver improvements.

5. References

1. The use of low-pass filters for reducing adjacent-channel interference in the m.f. broadcasting service. CCIR Study Groups, Period 1966 – 69, Document X/16-E, 8th January 1968.

2. NETZBAND, R. *and* SUVERKRUBBE, R. 1968. The effects of appropriate bandwidth limitation on the transmission and reception of a.m. sound broadcasting. *E.B.U. Rev.*, 1968, **109A**, pp. 115 – 124.

3. SUVERKRUBBE, R. 1969. System bandwidth and channel spacing in a.m. sound broadcasting. *E.B.U. Rev.*, 1969, **116A**, pp. 160 – 163.

4. COLEBROOK, F.M. Demodulation. *Wireless Engr.*, 1932, **IX**, 106, p. 394.

5. APPLETON, E.V. *and* BOOHARIWALLA, D. 1932. The mutual interference of wireless signals in simultaneous detection. *Wireless Engr.*, 1932, IX, 102, pp. 136 – 139.

6. MOULLIN, E.B. 1932. The detection by a straight line rectifier of modulated and heterodyne signals. *Wireless Engr.*, 1932, XI, 106, pp. 378 – 383.

7. Frequency response characteristics of four a.m. receivers. BBC Research Department Report No. 1969/34.

8. SHORTER, D.E.L., MANSON, W.I. *and* STEBBINGS, D.W. 1967. The dynamic characteristics of limiters for sound programme circuits. B.B.C. Eng. Monogr., 1967, No. 70.

9. CCIR, Documents of the XIIth Plenary Assembly, New Delhi, 1970, Recommendation 10/468.

10. CCIR, Documents of the XIth Plenary Assembly, Oslo 1966, Vol. V Recommendation 449, p. 36, Fig. 1, curve B.

11. ibid Report 339, pp. 141 – 144.

12. ibid Report 405, pp. 250 – 252.

SMW/AMM

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey